The Heart and Nervous System

THE HARVEIAN ORATION

1902

DAVID FERRIER

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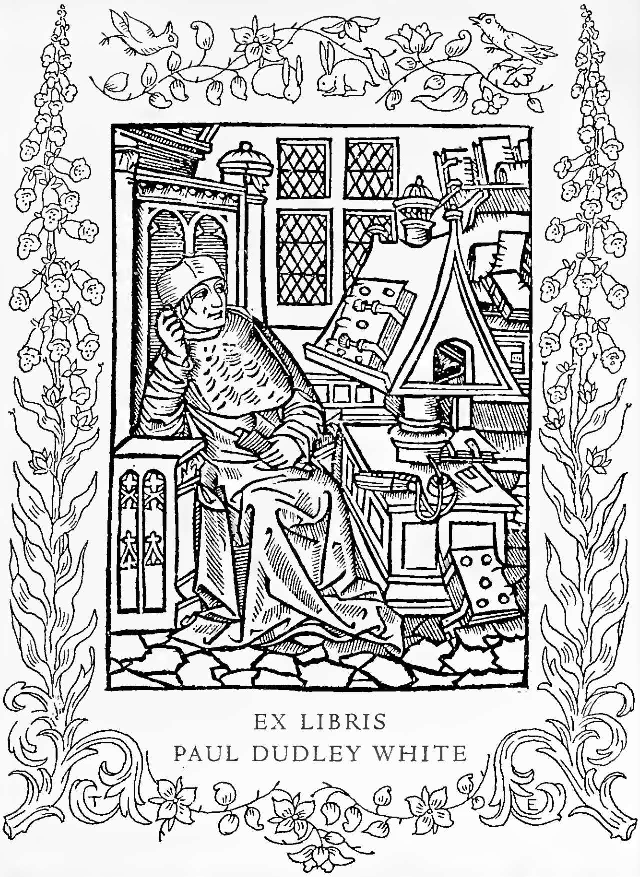

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BEING

THE HARVEIAN ORATION

Delivered before the Royal College of Physicians of London on October 18, 1902

BY

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London
JOHN BALE, SONS & DANIELSSON, Ltd.
OXFORD HOUSE
83-89, GT. TITCHFIELD STREET, OXFORD STREET, W.

1902

TO

Sir WILLIAM SELBY CHURCH, Bart., M.D.

PRESIDENT OF THE ROYAL COLLEGE OF PHYSICIANS,
LONDON.

THIS ORATION

DELIVERED AT HIS REQUEST

IS DEDICATED

AS A MARK OF ESTEEM.

The Harveian Oration,

1902.

Mr. President and Gentlemen,—I am certain I am but truthfully expressing the feelings of this important assemblage of the College of Physicians when I say that we one and all rejoice that our most exalted Fellow, His Gracious Majesty King Edward, has been happily restored to health and anointed King over a loyal and united nation—united as it has never been before in the history of our race. Our sovereign owes much to the medical profession, for twice, at least, he has been rescued from imminent

Note.—In the preparation of this address I have freely availed myself of the rich mine of material contained in the works of Tigerstedt *Die Physiologie des Kreislaufes*, 1893), von Bezold (*Die Innervation des Herzens*, 1863) and the well-known text-books of Foster and Schäfer. In particular I gratefully acknowledge much valuable help and counsel from my colleague, Dr. T. G. Brodie.

peril by the skill and devotion of our brethren. His Majesty has been singularly fortunate in having had on both occasions, as officers of his medical body-guard, the greatest living experts in the class of diseases by which he was assailed; and it is to us a legitimate source of satisfaction that our art has made such progress within the memories of us all as to have rendered it possible, in circumstances formerly almost hopeless, to save a life so precious to his subjects. If the King owes much to the medical profession, we on our part, gladly acknowledge the deep debt of gratitude which he has earned at our hands. He has at all times exhibited a sympathetic interest in our work, our needs and aspirations, and in particular by the magnificent endowment which he has secured to the metropolitan hospitals, he has done much to promote the cause of medical education and the welfare of his people. The illustrious Harvey, whose name, on this day of St. Luke, we are met to honour, was also fortunate in having in King Charles a sovereign deeply interested in scientific progress, who provided his trusted physician with many facilities for his observa-

tions and experiments, and often in person attended his demonstrations. It was to the king that Harvey dedicated his immortal treatise " De Motu Cordis " in poetical terms of comparison between the heart and body and the soverign and body politic.

> " The heart of animals is the foundation of their life, the sovereign of everything within them, the sun of their microcosm, that upon which all growth depends, from which all power proceeds."

It would be as difficult to understand vital functions, the conditions of health and disease, apart from the circulation of the blood, as it would be to explain the movements of the heavenly bodies without the law of gravitation. Harvey, as has been truly said, is the Newton of physiology. His " Exercitatio " is such a complete and closely reasoned proof of the circulation, that in the 274 years that have elapsed since its publication nothing of material consequence has been added to the cogency of his arguments ; and his demonstration of the movement of the blood in a circle is a model of exposition which cannot be surpassed by any lecturer on physiology at the present day. Harvey's work deals essentially with the

mechanics of the circulation, and in this he practically reached finality. But he naturally pondered over many cognate problems which have continued to exercise physiologists and psychologists to the latest times. It was evidently his intention to deal with these in a separate treatise, for, among other things, in his second letter to Riolan, he says :—

> "We also observe the signal influence of the affections of the mind when a timid person is bled and happens to faint. Immediately the flow of blood is arrested, a deadly pallor overspreads the surface, the limbs stiffen, the ears sing, the eyes are dazzled or blinded. . . . And what indeed is more deserving of attention than the fact that in almost every affection, appetite, hope or fear, our body suffers, the countenance changes, and the blood appears to course hither and thither. . . . But here I come upon a field where I might roam freely and give myself up to speculation. And indeed such a flood of light and truth breaks in upon me, occasion offers of explaining so many problems, of resolving so many doubts. . . . that the subject seems almost to demand a separate treatise. And it will be my business in my "Medical Observations" to lay before my

reader matter upon all these topics which shall be worthy of the gravest consideration."[1]

Harvey's speculations on these and kindred subjects, if his "Medical Observations" had come down to us, would have been of exceptional interest, though we cannot doubt that in the light of modern research they would have appeared but inchoate, as our own will doubtless so seem to those who come as many years after us as we are from Harvey. For the language of the physiologist is but a reflex of the state of knowledge of his day, and his explanations do not transcend those of the sciences on which his own is based. In his exposition of vital phenomena, Harvey shows himself still trammelled, and unable altogether to emancipate himself from the notions of Aristotle and Galen. He speaks, like Galen, of the heart as being an "elaboratory, fountain and perennial focus of heat" (second epistle to Riolan):—not, however, in virtue of its proper substance, but because of its contained blood. Though he scouts the idea of the calidum innatum as transcending the qualities inherent

[1] Harvey's Works by Willis, p. 129 — slightly transposed.

in the living heart and blood, or attributable to anything " of a sublime, lucid, ethereal, celestial, or divine nature," he naturally, in the then state of scientific knowledge, failed to master the problem of the source of animal heat. This was only possible more than 200 years after his time by the discoveries of Black, Priestley, Lavoisier, and others on the nature of combustion, and by the researches of modern physiologists on the metabolism of the tissues, and the foci of heat production in the body. We now know that there is no more innate heat in the heart than is evolved by its own intrinsic muscular contractions. Neurology in Harvey's time consisted largely in speculations as to the seat of the rational soul, and the mode of generation and distribution of the animal spirits to the various organs of the body. Little or nothing was known of the relations of the heart to the nervous system. Harvey had, however, some obscure conceptions as to the difference between "natural" and animal motion. He says :—

> "There are some actions and motions the government or direction of which is not dependent on the brain, and which are therefore

called 'natural.' . . . Many animals are endowed with both sense and motion without having a common sensorium or brain, such as earth-worms, caterpillars of various kinds, chrysalides, &c. So also do certain natural actions take place in the embryo, and even in ourselves, without the agency of the brain."[1]

But he looked upon all these "natural," visceral, or reflex, actions as proceeding from the power of the heart and dependent on it, while the animal motions alone necessitated the controlling influence of the brain. During Harvey's lifetime, however, Thomas Willis was laying the foundations of a more exact neuro-physiology. His work on the descriptive anatomy of the brain, the arrangements of its blood-vessels, the distribution of the cranial nerves, and the relations of the vagus and intercostal, or sympathetic nerves to the thoracic and abdominal viscera contains much of enduring value. Amid much fanciful speculation as to the functions of the different parts of the brain and the nature of the animal spirits, he came near formulating a true con-

[1] On Generation—Harvey's Works by Willis, p. 432.

ception of the nature of reflex action ; and in particular he clearly differentiated between the nerve centres governing the viscera from those which regulate the functions of animal life. He regarded the cerebellum as the centre of the visceral functions, a view which he was led to adopt, mainly by the anatomical connections which he thought he could trace between this organ and the vagal and sympathetic nerves.

> "When some time past I diligently and seriously meditated on the office of the Cerebel, and revolved in my mind several things concerning it, at length, from Analogy and frequent Ratiocination this (as I think) true and genuine use of it occurred : to wit, that the Cerebel is a peculiar fountain of animal Spirits designed for some work and wholly distinct from the Brain. The office of the Cerebel seems to be for the animal Spirits to supply some nerves by which involuntary actions (such as the beating of the heart, easie Respiration, the Concoction of the Aliment, the protrusion of the Chyle and many others), which are made after a constant manner unknown to us, or no, are performed."[1]

Willis, as we know, was wrong as to his localisation, but in this and other passages he

[1] "The Anatomy of the Brain," chapter xv.

not obscurely foreshadowed the distinction between the splanchnic and somatic systems of nerves rendered more precise in recent years.

Harvey knew that the heart of a cold-blooded animal would continue to beat when removed from the body, and even when cut to pieces, each portion continuing to execute its own rhythmical contractions. Though he does not specially discuss the cause of the heart-beat, yet one may gather from many passages in his writings, that he considered the heart to be endowed with an inherent activity of its own, independently of the brain and nervous system. The discovery, in more modern times, of the ganglia in the substance of the heart by Remak, Bidder and Ludwig, naturally led to the belief that its contractions are conditioned by rhythmical stimuli, proceeding from these intracardiac centres, just as the somatic muscles are normally excited to action by stimuli conveyed from the brain and spinal cord. Though, perhaps, the last word has not been said on this much-debated question, the balance of evidence, largely furnished by the ingenious and skilfully devised experiments of Gaskell, is in favour of the view that the

beat of the heart is due to an intrinsic rhythmical contractile power of the cardiac muscle, possessed by all parts in greater or lesser degree, but most marked in the venous sinus and auricle, whence a wave of contraction is propagated through the heart, leading the sequence and setting the pace to the other chambers. From this point of view the cardiac ganglia are merely peripheral ganglia of the efferent visceral fibres of the vagus, analogous to those of the visceral system of nerves in general. The heart, however, in its normal relations is not a mere mechanical pump, automatically working so many times a minute and turning out so many gallons of blood per diem in steady and regular flow. The needs of the organism are ever changing, and the heart and vascular system are ever adapting themselves in accordance therewith. There is scarcely an act, or thought, or feeling which does not reflect itself in the rate of the heart and state of the pulse. The explanation of these variations is to be sought for in the relations which subsist between the central nervous system and the heart and blood-vessels. Though to the physiologist this is a

well-worn theme, I trust that in my endeavour to bring into line the various conditions, physical and mental, which influence the circulation, it will not be considered unworthy of my learned audience if I sketch the principal facts and stages in the development of our knowledge of this subject.

The heart and blood-vessels, together with the walls of the hollow viscera, glands and non-striated muscles of the hair bulbs, as well as certain striated muscles derived from the lateral plates of the mesoblast, are innervated by the great system of visceral or splanchnic nerves, the differentiation of which from the somatic, or those which supply the organs and muscles of animal life, is the distinguished merit of Gaskell. And it is gratifying to think that also to other countrymen than Harvey, notably Langley, we owe in large measure what is known respecting the distribution of the ultimate ramifications of this great system of nerves. The visceral nerves consist of two sets, possessed of opposite functions, viz., motor and inhibitory—terms which are applicable to their action on the heart, blood-vessels, and hollow viscera.

The most epoch-making discovery in reference to the innervation of the heart was the observation of the brothers Ernst and Edward Weber[1] in 1845, that electrical irritation of the vagus caused the heart to beat more slowly or to stop altogether for a time in the state of diastole. This fact was an altogether new one in neurology and has been far-reaching in its consequences and application. Through the vagi the cardiac centres exercise a more or less constant restraining influence, so that when they are cut the heart beats more quickly. This effect was observed both by Willis and Richard Lower, but both regarded it as essentially of a paretic nature due to cutting off the main stream of animal spirits. Willis says :—

> "And here it may be rightly inquired into whether the pulse of the heart so necessarily depends on the influence of the animal spirits through the nerves, that it being hindered, the action of the heart should wholly cease? For the decision of this we once made a trial of the following experiment on a living dog. The skin about the throat being cut longways, and the trunk of both the wandering pair being separ-

[1] *Handwörterbuch d. Physiologie*, Bd. iii., 1846.

ated apart, we made a very strict ligature, which being done the dog was presently silent and seemed stunned, with a great trembling of the heart."[1]

Willis imagined that the sympathetic fibres of the cardiac plexus were able by a kind of anastomosis to supply the animal spirits after the vagi were divided. The totally different function of the sympathetic was first demonstrated in 1866 by von Bezold,[2] who found that stimulation of the filaments proceeding from the ganglion stellatum—derived, as it has been proved by subsequent researches, from the upper thoracic anterior roots—caused effects entirely antagonistic to those of the vagus, viz., acceleration of the rhythm and increased force of the cardiac contractions. The visceral system also contains sensory or afferent fibres, which are the medium of communication between the viscera and the sensorium, but the mode of origin, course and termination of these nerves are less accurately known than those of the efferent class. The heart, like the viscera, is in normal conditions but poorly endowed

[1] "Anatomy of the Brain," chapter xxiv.

[2] "Die Innervation des Herzens," 1863.

with sensibility, and is barely, if at all, sensitive to tactile stimuli. This fact was first demonstrated by Harvey in the case of the son of Viscount Montgomery, whose heart had been exposed by destructive ulceration of the chest wall in the præcordial region. This interesting patient was brought under Harvey's notice by King Charles. Harvey relates :—

> "I carried the young man himself to the king, that His Majesty might, with his own eyes behold this wonderful case: that in a man alive and well, he might, without detriment to the individual, observe the movement of the heart, and with his proper hand even touch the ventricals as they contracted ; and his Most Excellent Majesty, as well as myself, acknowledged that the heart was without sense of touch, for the youth never knew when we touched his heart except by the sight or the sensation he had through the external integument."[1]

The heart, however, is sensitive to severer forms of stimuli, and more particularly to states of abnormal tension. It is as Budge found[2] more sensitive towards the base, and less so

[1] "On Generation," Willis's translation, p. 384.
[2] Wagner's *Handwörterbuch*, Band iii., p. 485.

towards the apex. It is generally stated in text-books of physiology that the vagus is the sensory nerve of the heart. This, however, though apparently the case in frogs,[1] in which the vagus and sympathetic nerves run throughout in the same sheath, is not the whole truth as regards man or even animals in general. For after section of both vagi in a cat, Goltz found that pinching, or otherwise irritating, the heart caused reflex movements of the whole body. Though, as has been already remarked, the afferent fibres of the visceral system have not been experimentally determined with the same precision as the efferent, there are many reasons for believing that they are connected with the same spinal segments. This is borne out by Head's brilliant work on the relations between visceral disease and cutaneous pain.[2] Pursuing Ross's hypothesis that the viscera receive their sensory fibres from the same segments of the spinal cord as those from which the somatic sensory roots

[1] Goltz, *Virchow's Archiv.*, vol. xxviii., 1863.

[2] "On Disturbances of Sensation with Special Reference to the Pain of Visceral Disease." *Brain*, vol. xvi., 1893.

arise along which the pain is referred, he has succeeded in mapping out with marvellous definition the segmental relations of the sensory nerves of the various viscera. From these it appears that painful conditions of the heart refer not only into the regions connected with the vagi, but also into those of the upper dorsal segments whence the heart also receives its chief motor supply. The sensory nerves of the heart, therefore, lie not only in the vagus, but also in the rami communicantes of the upper dorsal nerves. What is the respective origin of these nerves in the heart is not as yet certain, but the recent investigations of Köster[1] indicate that the depressor nerve, the afferent nerve of the heart, *par excellence*, is in reality the sensory nerve of the aorta and not of the heart itself. The centres, both of the cardiac inhibitors and accelerators and augmentors are situated in the medulla oblongata—not in the cerebellum, as Willis supposed—the former in the vagal nucleus, where a pin-prick will arrest the heart, the latter in a point not yet accurately determined.

[1] *Ueber die Ursprung des N. Depressor*, *Neurologisches Centralblatt*, 1901, p. 1032.

These cardiac centres are in a more or less continuous state of so-called automatic activity, which is capable of being exalted, depressed, or otherwise modified by impulses proceeding from the heart itself and blood-vessels, from the somatic and splanchnic periphery as well as from the higher regions of thought and feeling.

We have, as a rule, no direct voluntary control over the heart's action—perhaps a wise provision of Nature against the temptation to try foolish and dangerous experiments. Cases, however, are on record in which, apparently hy voluntary effort, the action of the heart has been inhibited or rendered almost imperceptible. The best authenticated instance of this kind is that of Colonel Townsend (related by Cheyne in his "English Malady," 1733), who was able at will to throw himself into such a state of suspended animation that his heart and breathing ceased to be appreciable by ordinary tests. More wonderful things have been related of the Indian fakirs. We do not as yet know the real mechanism of this voluntary hybernation, but Ed. Weber proved on himself that the action of the heart can be reduced *ad*

deliquium animi by voluntary compression of the chest and forcible expiration with the glottis closed. This exerts such pressure on the great veins as completely to obstruct the flow of blood through the heart and to cause it to stop for several beats. Some of the cases of apparently direct voluntary control over the heart's action may be, therefore, accounted for through the medium of the respiratory mechanism; but there are others[1] in which the rate of the heart has been capable of acceleration at will, independently of the respiration and without calling up special ideas. In all such instances there has been also unusual power over the voluntary muscles.

Like the heart, the calibre of the blood-vessels is regulated by mutually antagonistic sets of nerves—the vaso-constrictors (vaso-motor) and the vaso-dilators (vaso-inhibitory). That the lumen of the blood-vessels was subject to variation under the influence of the nervous system was postulated long before it was actually demonstrated. The credit of this prevision has been assigned to various writers.

[1] Tarchanoff, "Pflüger's Archiv.," Bd. xxxv., 1884; also Pease, *Boston Med. and Surg. Journal*, May, 1889.

Harvey, as we have seen, intended to discuss the subject in his "Medical Observations." The philosopher Malebranche[1] is said to have propounded a vaso-motor theory of emotional expression according to which the flow of vital spirits to the brain and the organs was regulated by a special system of nerves. But Willis appears to have first actually demonstrated the nerves of the blood-vessels and to have indicated their true function; for he describes nerves from the cardiac and abdominal plexuses as accompanying the blood-vessels, which he graphically likens to twigs of ivy embracing and surrounding their trunks and branches. Of their function, in speaking of the solar plexus, he says:—

> "That from this plexus many fibres and shoots going forth are inserted into the Trunk of the Aorta nigh its descending, and that these reaching towards the intestines accompany the Blood-carrying vessels, and in several places climb over them; from hence it may be inferred that nerves also in the Abdomen are like Bridles and Reins cast on the sanguiferous Vessels, which, either by straining or pulling them together, may

[1] Quoted by Lange, *Ueber Gemüthsbewegungen*, 1887.

sometimes retard, sometimes incite the course of the blood according to the needs of the lower Viscera."[1]

The tightening or relaxation of the grip of the vaso-motor nerves on the blood-vessels, imagined by Willis, was shown by the discovery of Henle, in 1840, of the muscular nature of the middle coat of the arteries to be a contraction or relaxation of the walls of the blood-vessels themselves. But the actual proof of the action of the vaso-motor nerves was first given in 1851 by Claude Bernard,[2] in the well-known dilatation of the vessels of the rabbit's ear on section of the cervical sympathetic, followed almost immediately by the demonstration of the converse results on electrical stimulation of the distal end of the cut nerve by Bernard himself, Brown-Séquard,[3] and Waller.[4] Similar phenomena were speedily proved to obtain in reference to the vessels of the abdomen, the limbs, and most of the organs of the body. The blood-vessels are normally in a state of tone or semi-contrac-

[1] Chapter xxvii., p. 138.
[2] Comp. Rend. Biol., 1851, p. 163.
[3] *Philadelph. Med. Examiner*, Aug., 1852.
[4] Comp. Rend., 1853, p. 378.

tion, which is kept up mainly by the nervous system. The centre which governs the calibre of the blood-vessels is situated in the pons-medulla, probably in the group of cells known as the antero-lateral nucleus—the homologue of the cells of the intermedio-lateral tract of the spinal cord (Gaskell). Hence on section of the cord below this point there is extensive vaso-dilatation, with an enormous fall in the blood pressure. But though this is the chief centre of vaso-motor regulation, there is evidence that there are also subsidiary centres in the cord itself. For, after section below the medulla oblongata, the vessels after a time regain a considerable amount of tone, and reflex alterations in their calibre can be elicited by appropriate stimuli. The blood-vessels also possess an intrinsic activity similar to that of the heart itself, and exhibit slow rhythmical variations in calibre; and the recent experiments of Bayliss[1] prove that they respond to mechanical variations in internal pressure—constricting or relaxing, with a rise or fall respectively. The antagonistic nerves, the vaso-dilators, the homologues of the cardiac

[1] *Journal of Physiology*, xxviii., p. 220, 1902.

inhibitors, indicated by Schiff, were first clearly demonstrated by Bernard[1] in 1858, in the chorda tympani. (Electrical irritation of the branch of this nerve distributed to the submaxillary gland was found to cause such a degree of vascular dilatation that the blood flowed from the veins in jets and arterial in hue—a condition entirely independent of the function of the gland as such, inasmuch as it occurs with the same distinctness when the function of the salivary gland has been paralysed by atropine. The phenomenon is a pure instance of vaso-dilatation.)

Bernard's discovery of the vaso-dilators of the chorda tympani was followed in 1863 by that of Eckhard[2] of the vaso-dilator action of the nervi erigentes, and the existence of a special set of vaso-dilators running in separate channels from the constrictors was thus conclusively established. Subsequent researches have shown that vaso-dilators exist also in other nerves, which at first sight appear to contain only vaso-constrictors. Their presence, however, is only masked by the greater number

[1] *Journ. de Physiologie*, i., pp. 237 and 649.
[2] Beitr. 3. Anat. u. Physiol., iii., p. 123.

and greater excitability of the constrictors, but when special methods of stimulation are employed, the action of the vaso-dilators is made clearly manifest. All the organs supplied with vaso-constrictors are furnished also with vaso-dilators, but the proportion differs, and in some organs, such as the brain and lungs, it is still a question whether there are any vaso-motor nerves at all. In reference to the lungs, in which Bradford and Dean,[1] as well as François Franck,[2] claim to have demonstrated the existence of vaso-motor nerves, the recent experiments of Brodie and Dixon[3] are of special importance and significance. They found that no change in the calibre of the pulmonary arterioles could be produced by direct stimulation of any of the fibres proceeding to, or emanating from, the stellate ganglion. Further, when the lungs were perfused with blood containing suprarenal extract, which, as has been shown by Schäfer and Oliver,[4] usually causes constriction of the

[1] *Journal of Physiology*, 1894, vol. xvi., p. 34.
[2] *Archives de Physiologie*, xxvii., pp. 744 and 816, 1895.
[3] Brodie: "Arris and Gale Lectures on the Pulmonary Circulation," *The Lancet*, March 22, 1902, p. 803.
[4] *Journal of Physiology*, vol. xviii., p. 230, 1895.

blood-vessels, no such results occurred in the pulmonary blood-vessels but rather the reverse. This led to the discovery that when the arterioles of organs, otherwise occluded by suprarenal extract, have had their vaso-motor nerves previously paralysed by apocodeine or cocaine, perfusion with suprarenal extract causes dilatation instead of constriction. That this result is not due to paralysis of the muscles of the arterioles is proved by perfusion with chloride of barium, which causes intense constriction and complete stoppage of the outflow. These experiments show, therefore, that suprarenal extract acts by stimulating the nerve-endings of vaso-constrictor nerves, and that there is no evidence of such in the pulmonary blood-vessels.

Generally, it may be said that those organs in which it is necessary for occasional purposes to have an active flow of blood, such as the salivary glands, kidney, and generative organs, are specially provided with vaso-dilators, which sometimes run in separate channels. The centres of the vaso-dilator nerves have not been determined with the same precision as those of the constrictors. It is probable that

they are related to the segments of the cord, from which they respectively arise. This at least is true of the nervi erigentes, for when the cord is divided above their origin their function can be excited or inhibited reflexly just as in normal conditions (Goltz). Vaso-dilatation is not, however, always an active effect, but sometimes only a cessation of normal tone; and there is one afferent nerve, the action of which is always vaso-dilatation. This—the depressor, discovered by Ludwig and Cyon in 1866—plays a very important *rôle* in the regulation of the circulation. It is one of the afferent or sensory nerves of the heart, arising either in the heart itself, or, according to the researches of Köster mentioned above, at the base of the aorta. Stimulation of this nerve, arising normally from states of tension, inhibits the action of the vaso-motor centre and causes intense dilatation, more particularly of the abdominal system of blood-vessels. It is by the interdependence of the cardiac and vaso-motor nerve mechanisms, and the manifold ento- and epiperipherical stimuli by which they are influenced, that the heart is protected from undue strain; that great and prolonged varia-

tions in the differential pressure between the arteries and veins are obviated or compensated; and that each organ obtains its due measure of blood in accordance with the calls made upon it. We cannot doubt that the cardiac and vascular reflexes are essentially of a protective nature, like reflex actions in general. But though the teleological significance of many of these is obvious, the usefulness of others is still involved in obscurity. We can readily understand why, as Marey has beautifully demonstrated, the heart should be inhibited when the resistance in front is too great for it to contend with safely; and why, under similar conditions, impulses should be conveyed by the depressor nerve, which diminish the resistance by dilating the great vascular area of the abdomen. In this we have an instance of the protective action of the vascular and cardiac reflexes on the heart itself. On the other hand, the vagus may be called into play with the view of protecting other organs, especially the brain, from undue pressure and congestion. Great rise of intracranial pressure causes slowing of the heart. This is brought about by direct action on the

medulla itself. For, as Franck has shown, when the brain is isolated from the rest of the body, with the exception of one vagus, injection of blood into the carotid causes the heart to beat faster or slower according to the degree of pressure exerted. And it has been argued by Roy and Adami[1] that in this we have a protective against cerebral congestion, inasmuch as the slowing of the heart from increased intracranial tension is brought about by action on the medullary centres and not from within the heart itself. The protective mechanism of cardiac acceleration is exemplified in the increased rapidity of the heart, which is excited by conditions which tend to lower the pressure in the bulbar centres—such as change from the horizontal to the vertical posture, and under all conditions which lead to dilatation of any large vascular area.

All organs in a state of activity are able, either by local action on the blood-vessels or by reflex vaso-dilatation, to secure an increased flow of blood. If the vascular area thus dilated is at all extensive the lowering of blood pres-

[1] *Philosophical Transactions*, B. 183, p. 251, 1893.

sure, which would be thus induced, is counteracted by greater rapidity of the heart, and constriction of the vessels in other regions. Thus dilatation of the abdominal vessels during the act of digestion is accompanied by the proverbial coldness of the skin, and the constricted vessels and cold feet of active brain work are familiar to us all. These instances of the obviously protective action of the cardiac and vascular reflexes might be multiplied indefinitely, but there are many others the significance of which is not so apparent. Among these may be mentioned the reflex inhibition of the heart, which is so easily excited by irritation of the air passages[1] and lungs.[2] There is little reason to doubt, however, that like the similar inhibition of the respiration from irritation of the interior of the heart,[3] they play an important part in the mutual regulation of the intimately interdependent functions of the circulation and respiration. The cardiac, vaso-motor, and respiratory

[1] Dogiel, Holmgren.

[2] Brodie and Russell: *Journal of Physiology*, vol. xxvi., p. 92, 1900.

[3] Franck: *Travaux du Laboratoire de Marey*, 1880.

centres are all closely inter-related to each other. Of these the respiratory is most readily influenced, both from the periphery and the higher centres, and it is not improbable that many of the variations in cardiac rhythm and vascular tone so induced are in reality conditioned only mediately through the respiration. With the exception of the depressor and the nerves of the air passages and lungs, moderate stimulation of perhaps all other sensory nerves, general and special, causes constriction of the blood-vessels, with a rise of blood pressure and acceleration of the heart. This, however, is a rule liable to many exceptions, the conditions of which are not as yet in all respects satisfactorily determined.

In states of exhaustion, and when the stimulation is of a sudden or intense character, more particularly when of visceral origin, there is a fall in blood pressure and reflex inhibition of the heart, which, in certain conditions, may be fatal. As an instance of this kind one may quote Goltz's famous "Klopfversuch," by which it is shown that a smart tap on the abdomen of a frog causes stoppage of the heart and dilatation of the splanchnic blood-

vessels. The vascular dilatation so induced is so enormous that practically the whole of the blood in the body is accumulated in the abdomen, and the animal dies by hæmorrhage into its own veins. The heart may continue to beat, but to no purpose; its cavities are empty and no blood passes through it. It is, in all probability, to vaso-motor paralysis of this nature that the symptoms of surgical shock are due, as has been maintained by Lauder Brunton,[1] Crile,[2] and others. In this relation also the recent researches of Embley[3] on the cause of death from chloroform are deserving of the most attentive consideration. In the early stages of chloroform inhalation the heart is weakened and more susceptible to the influence of the vagus. The inhibitory mechanism is also more excitable, so that there is thus a twofold risk of permanent inhibition of the heart, especially when the blood pressure is greatly reduced. Fortunately, in profounder anæsthesia the cardiac reflexes are almost abolished, so that in addition to its

[1] "Syncope and Shock," 1873.
[2] "Surgical Shock," 1897.
[3] *British Medical Journal*, April, 1902.

beneficent action in annulling pain, chloroform minimises the otherwise dangerous, or even fatal, depression that might result from severe surgical procedure.

Most, if not all, of the cardiac and vascular reflexes are capable of being elicited through the medullary centres alone, and they can be obtained with great facility, as Brodie and I have found, in decerebrate animals.

The cardiac and vascular reflexes have an especial bearing on the circulation in the brain. The cerebral circulation has many features of an exceptional character. The doctrine propounded by Monro Secundus, supported by Kellie and Abercrombie, and most ably advocated at the present day by Leonard Hill,[1] is that, as the cranium is a closed cavity and the brain substance incompressible, the quantity of blood within the skull must practically be at all times the same—the blood flowing out of the veins to make room for that flowing in by the arteries—those conditions only being excepted in which fluid or other matter is effused or secreted by the blood-vessels, for, in such circumstances, a quantity of blood equal

[1] "The Physiology of the Cerebral Circulation," 1896.

in bulk to the effused matter will be pressed out of the cranial cavity. It has been argued in opposition to this doctrine that the free ebb and flow of the cerebro-spinal fluid between the cerebral and spinal cavities must allow of considerable variation in the volume of blood in the cranium, but under normal conditions the amount of this fluid is so small as to be practically a negligible quantity. The variations in blood-supply extend for the most part only to the relative proportion between the arterial and venous. The brain fills the cranial cavity as a hand a glove, and is closely appressed to the interior of the skull-cap. The pressure exerted from within outwards varies greatly; directly with the venous, and only proportionately with the arterial pressure. It is increased with each pulsation of the heart, and with each expiration if at all forcible. The average is about 100 millimetres H_2O, but the pressure is of importance purely in its bearing on the circulation. The functions of the brain cease if the arterial pressure is too low to cause an effective flow throughout the capillaries, or if the venous pressure is too high to permit of the arteries emptying them-

selves. In either case the circulation in the brain fails, and loss of consciousness ensues. The brain tissue, however, as such can carry on its functions at any pressure from zero up to 50 millimetres of Hg. or more. Thus, in a patient who had been trephined, and the brain, therefore, exposed to atmospheric pressure, Hill found that the intracranial pressure fell slightly below zero when he stood upright ; and in a case of strychnine convulsions the pressure was estimated at 50 millimetres Hg., and yet both patients retained their mental faculties unimpaired. Up to the present no satisfactory experimental evidence has been furnished as to the existence of vaso-constrictors or vaso-dilators of the cerebral blood-vessels. Morison,[1] however, and Gulland[2] have both, within the last few years, demonstrated the presence of nerve plexuses on the vessels of the pia mater in all respects like those of vaso-motor nerves elsewhere. Yet no active change in the calibre of the cerebral blood-vessels can be produced by stimulation of the cervical sympathetic or stellate ganglion

[1] *Edinburgh Medical Journal*, 1898.

[2] *British Medical Journal*, vol. ii., 1898, p. 78.

—practically the whole of the sympathetic supply to the carotid and vertebral arteries—or even, according to Hill, of the central end of the cut spinal cord or the vaso-motor centre itself. The opposite results obtained by Nothnagel, Cavazzani, and others are attributable to defective methods of experiment, which do not differentiate between active and passive variations in the calibre of the vessels, or exclude changes due to mere atmospheric exposure. This negation of vaso-motor regulation of the cerebral blood-vessels seems to be in flagrant contradiction with the positive demonstration of nerves accompanying the vessels of the pia mater, as well as with other facts, such as the apparently independent variations of the plethysmographic volume records described by Mosso, and we can scarcely doubt that there must be some intrinsic mechanism which can secure a greater flush of blood in one part as compared with another in an organ in which there is proved localisation of function. Roy and Sherrington[1] believed that they had discovered such a mechanism in the products of cerebral meta-

[1] *Journal of Physiology*, xi., p. 103, 1890.

bolism dissolved in the lymph which bathes the cerebral arterioles—products capable of inducing variation in the calibre of the blood-vessels in correspondence with local variations in functional activity. This, however, has been contested by Hill. Brodie and I have, however, succeeded in rendering it more than probable that the cerebral blood-vessels are under the influence of vaso-motor nerves, though so far we have not been able to determine their origin and course.

As already mentioned, perfusion with suprarenal extract of an organ supplied with vaso-motor nerves causes constriction of the arterioles so that the flow through the capillaries is diminished or altogether stopped. It was found by Biedl and Reiner[1] that injection of suprarenal extract into the cerebral end of the carotid caused a rise of blood pressure in the circle of Willis, and diminution of the outflow from one of the lateral sinuses—a result which might be attributed to the action of adrenalin on the terminals of cerebral vaso-motor nerves. But the conclusion is not free from fallacy owing to the non-determination of the condi-

[1] *Pflüger's Archiv*, Band lxxix., p. 158, 1900.

tions affecting the outflow from the other sinus. This fallacy, however, is eliminated by Brodie's method. By the injection of adrenalin into the basilar artery of the carefully removed brain, and measurement of the outflow from the torn sinuses, he found that with a moderate amount there was distinct diminution of the outflow, and complete stoppage when the dose of the extract was increased. This appears to afford satisfactory proof of the existence of cerebral vaso-constrictors, though, as compared with those of other organs, their influence is relatively slight; and there seems, therefore, no further reason for doubting the existence of some intrinsic vaso-motor regulation of the cerebral circulation. The cerebral circulation, however, varies for the most part only passively with the circulation as a whole. The blood is so disposed in the body that it may be temporarily diverted from one region in order to secure a richer supply to another which requires it. It has been calculated that when the body is at rest the thoracic and abdominal organs contain from 60 to 70 per cent. of the whole blood. In the state of activity this percentage is reversed. Thus Ranke estimates that in

the state of rest the neuro-muscular apparatus contains on the average only about 36 per cent. of the blood, while in the state of activity the percentage is nearly doubled. The rapidity of the circulation in the brain in a state of activity is greater than in the state of quiescence or sleep. This is brought about by the constriction of the splanchnic and cutaneous blood-vessels through the agency of the vaso-motor centre. In illustration of this an ingenious apparatus has been devised by Mosso. When a person lies flat on a couch swinging on a horizontal axis, with the head and feet accurately counterpoised, the head goes down when the brain is at work; on the other hand, the feet sink when the individual falls asleep, indicating that the blood has returned to the extremities. In tranquil sleep a sound or any kind of sensory stimulus suffices to reverse the position of the head and feet, and that, too, when the stimulus has not been sufficient to cause the sleeper to awake or to retain any knowledge of the event. Every sensory stimulus of moderate intensity has the effect of raising the blood pressure by constriction of the cutaneous and splanchnic areas. We may

see in this a protective mechanism whereby impressions on the organs of sense not only awaken perception but provide the centres and apparatus of thought and volition with the means of energising in accordance with the needs of the occasion. The sensory nerves and vaso-motor centre therefore act, in the figurative language of Mosso, as "sentinels on the defensive, watching continuously, and sounding the alarm when danger is nigh." [1]

The circulation in the brain is largely dependent on the tone maintained by the vaso-motor centre. Conditions which materially lower the vascular tone, such as prostrating diseases, certain toxic agents, and the like, tend to induce cerebral anæmia and impairment of cerebral energy, especially in the upright posture. For though under normal conditions the influence of gravity is not appreciably felt, it becomes very apparent when the vascular tone is defective. Hence in such conditions syncope readily occurs when the individual is suddenly raised from the horizontal to the vertical position, or obviated when the positions are reversed. In a less degree the

[1] "Fear," p. 123, 1896.

failure of the cerebral circulation from defective blood pressure is seen in the heaviness and drowsiness which follow a heavy meal, with its consequent dilatation of the abdominal blood-vessels. Some individuals cannot do active brain work in the upright posture, and instinctively adopt such attitudes as favour the flow of blood to the head. The girding of the loins for active effort has its philosophy, according to Roy and Adami,[1] in the compression of the abdominal vessels, which raises the blood pressure and increases the output of the heart.

The influence of the blood pressure on the circulation of the brain naturally leads to a consideration of the influence of cerebral activity, more particularly states of feeling, on the heart and blood-vessels. This is a highly complex problem, and though it has actively engaged the attention of many eminent physiologists and psychologists, the results arrived at are neither altogether definite nor harmonious. The influence of states of feeling on the circulation is, however, so patent that at all

[1] "Waist Belts and Stays," *National Review*, November, 1888.

times and in all languages they have been expressed in terms of the heart. The very obvious display of emotional states in this manner has led James[1] and Lange,[2] particularly the latter, to regard the vaso-motor reactions and the conditions thus secondarily induced in the viscera as the essential basis of the vivid or so-called "courser" emotions, such as joy, sorrow, fear, and anger. There is much to be said in favour of the view that the organic sensations, primary or secondary to vascular changes, constitute an important factor of emotional states, but there are serious objections to regarding them as their essence. The sensations and emotions have their affective tone as such independently of the vascular concomitants, and it has been contended that the vascular reactions occur in point of time subsequently to the actual manifestation of the feeling in consciousness. Sherrington's[3] experiments have also an important bearing in this relation. When in dogs the spinal cord had been severed headward of all the sym-

[1] "Principles of Psychology."
[2] *Ueber Gemüthsbewegungen*, 1887.
[3] "Proceedings of the Royal Society," May 10, 1900.

pathetic nerves of the thoracic, abdominal, and pelvic viscera—thus separating the brain practically from all connection with these viscera, from the skin of the trunk and limbs, and the blood-vessels from the vaso-motor centre—yet these animals under appropriate stimuli exhibited indubitable signs and gestures expressive of pleasure, anger, fear, disgust, and the like. The same phenomena were observed even when in addition the vago-sympathetic nerves were divided, thereby rendering insensitive also the stomach, lungs, and heart itself. Unless we can assume with Ribot[1] that there is a *mémoire affective*, and with Dewey[2] that there is a revival in idea of the organic states that have in past experience been habitually associated with particular feelings, we must admit from these experiments that, apart from all vascular and visceral effects, emotions and passions are capable of being felt and expressed, at least in the domain of the muscles of animal life, with all their appropriate and characteristic gestures. We can scarcely doubt, however, with James that such evis-

[1] *Psychologie des Sentiments*, 1899.

[2] *Psychological Review*, 1895.

cerated and disembowelled emotions can only have been a mere simulacrum of those which would otherwise have thrilled throughout the whole frame of the animal. But even if we thoroughly recognise the immense importance of the visceral factor in emotion, it would be rash, if not altogether erroneous, to regard this, with Lange, as secondary only to vasomotor changes. For there are many facts—notably the novel and luminous experiments of Pawlow[1] on secretion—which prove that psychical states influence the processes of secretion not mediately through the circulation but directly through the secretory nerves of the glands. The most manifest organic expressions of emotion, however, are those in the domain of the circulation with which, for the present, we are more immediately concerned.

The observations of Binet and Courtier[2] show that every feeling, whether agreeable or painful, acts primarily as an excitant. The passage from the state of repose into the state of activity, intellectual or emotional, causes

[1] *Le Travail des Glandes Digestives*, 1901.
[2] *La Vie Emotionelle, L'Année Psychologique*, 1897.

vaso-constriction. The stronger the stimulus the greater the effect, and for this reason, perhaps, the more painful feelings and emotions, which can be more readily experimentally induced, cause more marked vaso-constriction than those that are more agreeable. The heart is accelerated, the respiratory rhythm is altered, becoming more rapid and more profound, with obliteration of the respiratory pause, and at the same time there is a general rise of blood pressure.[1] If the volume of the brain is simultaneously registered by the plethysmograph, as Mosso has described, and Brodie and I have verified, one observes almost constantly an increase. This seems to indicate that there is a relation of antagonism between the volume of the brain and that of the extremities. But this is not an absolute rule, for Mosso has observed that the oscillations in the brain volume do not in all respects run parallel to those of the extremities, probably owing to local variations in the cerebral blood-vessels themselves. Whether the quality of the sensation or emotion as such—*i.e.*, whether it be agreeable or disagreeable, pleasurable or pain-

[1] Binet and Vaschide, *ibid.*

ful—is always associated with characteristic and uniform changes in the circulation is still the subject of considerable difference of opinion. It is probable that the discrepancies are largely occasioned by the fact that the characters of feelings are, as maintained by Wundt, much more complex than can be expressed in simple terms of pleasure or pain. For besides being pleasurable or the reverse (Lust—Unlust), feelings are exciting or soothing (Erregung—Beruhigung), straining or relaxing (Spannung—Lösung), and vary in intensity. And Brahm holds[1] that each of these conditions has its specific influence on the circulation, hence the results may so vary in different individuals that absolute uniformity probably does not exist. Apart from the suddenness of the change from a state of repose to a state of activity, whether this be indifferent, such as mere surprise, or of a painful or pleasurable character, the balance of evidence is in favour of the view that pleasurable sensations and emotions are accompanied by vascular dilatation and low tension, while the contrary are associated with vascular

[1] *Experimentelle Beiträge zur Gefühlslehre, Philosophische Studien*, Band xviii., Heft i., 1901.

constriction and high-tension pulse. This is borne out, not only by experiments on normal individuals,[1] but by observations on the morbid states of joy and sadness in the typical forms of insanity.[2]

The vascular dilatation of pleasurable states of mind signifies also a more active circulation and exaltation of all the vital processes—dynamic and metabolic—while the opposite condition obtains in states of mental pain. Conversely, also, given the vascular and corporeal state arising spontaneously or induced artificially, usually associated with any particular mood, trains of thought and states of feeling corresponding therewith are apt to arise in consciousness. This, in all probability, as Lange indicates, is the origin of the use of stimulants and nervines of various kinds, which all nations and at all times have dis-

[1] Lehmann: *Die Körperlichen Äusserungen psychischer Zustände*, 1899.

[2] On this I might quote the observations of Dumas: *La Tristesse et la Joie*, 1900; Broadbent: "The Pulse," 1890; Maurice Craig: "Blood Pressure in the Insane," *The Lancet*, June 25, 1898; Dawson: "The Rôle of the Blood-supply in Mental Pleasure and Pain," *Journal of Mental Science*, February, 1900; and others.

covered for themselves. That "wine maketh merry the heart of man" is only a more picturesque statement of the truth I am endeavouring to convey in more didactic style. Pleasurable and painful emotions are thus not merely subjective states of consciousness, but at the same time objective corporeal conditions of exalted or depressed vital energy respectively, which manifest themselves not only in outward attitude and gestures but in the relative power of the organism to withstand debilitating agencies of all kinds. To promote the one and to combat the other is therefore to the physician not less important—and perhaps more a mark of therapeutic skill—than a judicious selection from the materia medica. There is thus a similarity, if not an identity, between the effects on the circulation of painful and pleasurable sensations and painful and pleasurable emotions, and at bottom they are probably based on the same physical substrata. Pain and pleasure are merely the subjective aspects of physiological conditions harmful or beneficial to the organism — a harmonious relation or the reverse between the processes of integration and disintegration.

As all the emotions, however complex, are founded ultimately on the affective tone accompanying the exercise of the organs of sensation in all their relations, visceral or somatic, the emotional and sensory substrata are one and the same. And it is not improbable that each organ has its own affective tone, its own centre, and contributes its own share to the general emotional result. Whether the feelings are conditioned from within or without, by presentation or representation, the effect on the circulation is the same. That which seems to constitute the chief difference between simple feelings and emotions is the relatively greater influence of the latter as compared with the former. Emotions are unitary composites of simple feelings and the resulting aggregate is much more powerful than any one of its individual elements. Fear, which is mental pain, causes greater acceleration of the heart, greater vascular constriction, and greater pallor than can be induced by mere physical pain. Not only is the circulation profoundly affected but there is a tendency to irradiation beyond the cardiac and vaso-motor into all the splanchnic functions, so that we observe *inter*

alia profuse perspiration, horripilation, and movements of the abdominal and pelvic viscera, which can rarely, if ever, be reflexly induced by any degree of peripheral stimulation. In its more intense forms fear may for ever arrest the heart-beat or so break down all the protective mechanism of the organism that flight, defence, or other means of adaptation are rendered impossible, and the animal falls an easy victim to the danger assailing it.

When we inquire by what mechanism the centres of thought and feeling influence the heart and blood-vessels—whether there are cortical cardiac and vaso-motor centres properly so-called, or whether the cerebral hemispheres act only indirectly upon the cardiac and vaso-motor centres of the medulla oblongata, we come upon a subject on which, in the present state of our knowledge, it is necessary to speak with caution, avoiding too confident or dogmatic assertion. Several observers[1] have described variations in the rate of the heart and tone of the blood-vessels as resulting from irritation of various portions of the cerebral hemisphere, particularly the motor area or

[1] Schiff, Bochefontaine, Danilewsky, and others.

adjoining region. But the careful experiments and weighty considerations advanced by François Franck[1] render it, I think, probable that all the cardiac and vascular effects that occur are merely the correlated concomitants of the functional activity of the motor centres, excited in a more or less obvious epileptic manner; or that the cerebral hemispheres are only the point of departure of stimuli which influence the cardiac and vaso-motor centres of the medulla oblongata in precisely the same way as those which originate in the periphery. The results are inconstant—sometimes acceleration, sometimes inhibition; they cannot be foretold; they do not vary with the point of stimulation; they have none of the features of the contra-lateral manifestations so characteristic of stimulation of the motor centres; and there is no good ground for assuming that there are any definite areas controlling respectively acceleration, inhibition, vaso-constriction, or vaso-dilatation. It is, indeed, probable that many of the reactions on the heart and blood-vessels which have been described as resulting from cortical excitation

[1] *Les Fonctions Motrices du Cerveau*, 1887.

are only mediately produced through the respiratory centre, which we know is to a considerable extent governed from the cerebrum. The cardiac and vascular centres in the proper sense of the term are in the medulla oblongata and the hemispheres are to them as much peripheral as the sensory nerves in general. The same may perhaps be affirmed of the so-called centres of the salivary and digestive glands recently described by Bechterew and his pupils.[1]

Through what centrifugal channels the cerebral hemispheres influence the cardiac and vaso-motor centres is not definitely ascertained, but they probably traverse the tegmentum beneath the corpora quadrigemina. For in this region electric stimulation, as Danilewsky, Lauder Brunton, myself, and others have shown, invariably produces such alterations of cardiac and respiratory rhythm and vascular tone as might well be regarded as signs of irritation of the paths by which the cortical centres transmit their influence to those of the

[1] *Die Corticalen Secretorischen Centra der Verdauungsdrüsen*, *Archiv für Anatomie und Physiologie*, *Physiologische Abtheilung*, Hefte iii. and iv., 1902.

medulla oblongata. We can, however, scarcely expect by artificial methods to reproduce the conditions underlying any particular emotion, and no one has yet succeeded in imitating, either by reflex or central stimulation, the blush so characteristic of the emotions of modesty or shame. But further to discuss these and kindred topics would lead me far beyond the limits of an occasion such as this.

My object has been to present to you a concise sketch of some of the principal relations of the heart to the nervous system which we have learnt since the time of the immortal Harvey. I have left many problems untouched, and as to those on which I have ventured I have, I fear, succeeded only in indicating how much is still hypothetical and uncertain. Doubtless some Harveian orator of the future, if he takes up the same theme, will be able to expound it more luminously in the light of fuller and riper knowledge. This will surely come if only we follow in the footsteps of our great master, and obey his wise injunction to "search out Nature by way of experiment."